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RESEARCH ARTICLE

Cheese Price Softening in the U.S.: Determining Effects from Excessive Cheese in the Market

Zuyi Wang[1] **Hernan Tejeda**[2] **Man-Keun Kim**[1*] **Wai Yan Siu**[3]

1. Department of Applied Economics, Utah State University, Logan, Utah, 84321, United States
2. Department of Agricultural Economics and Rural Sociology, Twin Falls Research and Extension Center, Twin Falls, University of Idaho, Idaho, 83844, United States
3. Haub School of Environment and Natural Resources, University of Wyoming, Laramie, WY 82072, United States

Abstract: The United States (U.S.) cheese sector has experienced continuous production and consumption growth since the 1990's with its market characterized as having oligopolistic behavior, signaling that prices respond to supply. Despite the steady industry growth, it experienced a recent multi-year period of declining prices. This paper addresses how growth towards an all-time record surplus of cheese, in response to excess milk production and export drops, weakened U.S. cheese prices. This study finds there is a significant short-run effect on price from overly expanded cheese supply, i.e., specifically taking a 2019 monthly average supply of 2.48 billion pounds, a 10% rise in cheese supply results in an immediate price decrease of 8.7%, translating to an average decline of USD 0.15/pound. The cumulative effect on its price from this 10% change results in a cumulative drop in cheese prices of 18.9%, approximately equal to a decrease of USD 0.34/pound. Findings provide relevant information to cheese, dairy producers and stakeholders, for milk production schedules, risk management and dairy policy analysis.

Keywords: Autoregressive distributed lag model; Cheese prices; Price softening; Supply growth

1. Introduction

The U.S. cheese sector has been steadily growing since the 1990s and has become among the most important commodities in the U.S. dairy agricultural economy. U.S. consumers are consuming twice as much cheese per capita as they did in 1980 [1]. Moreover, annual cheese production in the U.S. has been steadily growing from 6.94 billion lbs. in 1995 [2] to 13.1 billion lbs. in 2019 [3]; with

*Corresponding Author:
Man-Keun Kim,
Department of Applied Economics, Utah State University, Logan, Utah, 84321, United States;
Email: mk.kim@usu.edu

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supply growth increasing more rapidly in the recent period from 2015 to early 2019 versus the previous five years, i.e. 4.3% annum versus 2.2% annum, respectively. Despite the consumption growth, U.S. cheese markets experienced a steady decline in prices between 2015 and early 2019①. Industry analysts have described the drop in cheese prices as the result from an abundance in the supply of cheese, accompanied by increases in imports and drops in exports. This paper seeks to quantify market effects from an overly abundant growth in cheese supply that weakened its prices, and in turn, affect milk production prices due to milk production pricing mechanisms [4]. The findings of this study enhance our understanding of the relationship between cheese price and its supply, derived from (perishable) milk production, with significant implications for risk management, investment decisions, and potential policy analysis. As a result, agribusiness sectors and supply chain actors involved in cheese markets stand to benefit from this research paper, as it quantifies the impact of excessive growth of cheese supply in the market on both short-run and long-run prices. Moreover, these insights may provide valuable information for strategic decision-making within the cheese industry. Studying the price of cheese holds significant importance, primarily due to the dairy sector's prominent role as the main agricultural industry in several U.S. states, including California, Wisconsin, New York, Idaho, Michigan, and New Mexico, among others. Many of these states are also major cheese producers. In 2021, more than 42% of US milk fat was used for cheese production [5], and the daily consumption of cheese per person increased to 0.74 cup-equivalents (1 cup-equivalent = 1 cup milk) in 2021 from 0.36 cup-equivalents per person in 1981 [6]. Moreover, cheese exports have witnessed growth in recent years, with increased shipments to countries such as Mexico, the Middle East, Japan, Central America, the Caribbean, Korea, Australia, and Colombia in 2022. Hence, as previously mentioned, quantifying the impact of unprecedented growth in cheese supply may assist in providing valuable information for strategic decision-making within the cheese industry.

From U.S. Department of Agriculture (USDA) data, the amount of cheese surplus (beginning stock) in the U.S. grew from about 1 to 1.4 billion pounds between 2016 and 2019 [5], reaching record numbers, as shown in Panel A (highlighted within the blue oval) in Figure 1. The substantial increase in cheese storage began around 2008 in response to milk production exceeding its rates of use/consumption, and driving the milk surplus to produce cheese [7].② Cheese exports have constituted an average of 5.6% of yearly production since 2010. However recently, China and Mexico imposed retaliatory tariffs on U.S. dairy exports in the summer of 2018 as a consequence of a trade war; which resulted in annual cheese shipments dropping by 63% and 10% to China and Mexico; respectively [9]. Between 2010 and 2019 U.S. milk production increased by a total of 13.3% [3], and cheese production grew as well, but at a higher rate of 29.8% (3.3% per annum)—as observed in Panel B in Figure 1. Total cheese supply (sum of stocks, production, and imports) has likewise steadily increased, as shown in Panel C Figure 1, even more in the period 2016 to 2019 (blue oval) as mentioned previously. It is important to note that in 2019, cheese supply growth decreased dramatically as seen in Panel A and Panel C (gold oval).

The increased supply over time has had a notable impact on cheese prices, particularly during the period from 2015 to 2018 as depicted within the blue oval in Figure 2. However, in 2019, cheese prices increased and inventory remained rather steady given the minor cheese production increase of 0.8%, in comparison to 3.1% and 3.8% of the previous two years (Figure 2, yellow oval)③ accompanied by a rise in cheese exports of about 3%. As aforementioned, lower cheese prices also affected dairy producers' milk prices regulated through Federal Milk Marketing Orders (FMMOs), which govern about 75% of the US milk supply [11,12]. The price of cheese plummeted again in the spring of 2020 as the COVID-19 pandemic hit the U.S. (not shown in Figure 2). COVID-19 produced a significant and unexpected shift in cheese demand since a large portion of cheese consumption occurs through restaurants and school cafeterias, and these shut down during the 2nd quarter of 2020 [13]. At the same time, cheese consumption grew in family household cooking settings, though at a lower rate. The shift in consumption outlets as a consequence of the pandemic had varying effects on different agents along the dairy supply chain, as described by Wolf et al. [14].

Cheese prices may be sensitive to supply due to the oligopolistic behavior observed in the structure of the U.S. cheese market, as supported by previous studies by Mueller and Marion [15], Arnade et al. [16], and Bolotova and Novakovic [4]. That is in the classical oligopolistic market model, e.g., the Cournot model, market prices tend to be a function of supply [17]. The empirical strategy employed

① This study does not include price shifts during subsequent period of COVID-19 which is under a different study.

② Milk surplus (oversupply) is noted by average milk production costs being lower than prices; i.e. below perfect competition equilibrium levels [7].

③ In 2019, there was a significant slowdown in year-over-year milk production growth [10].

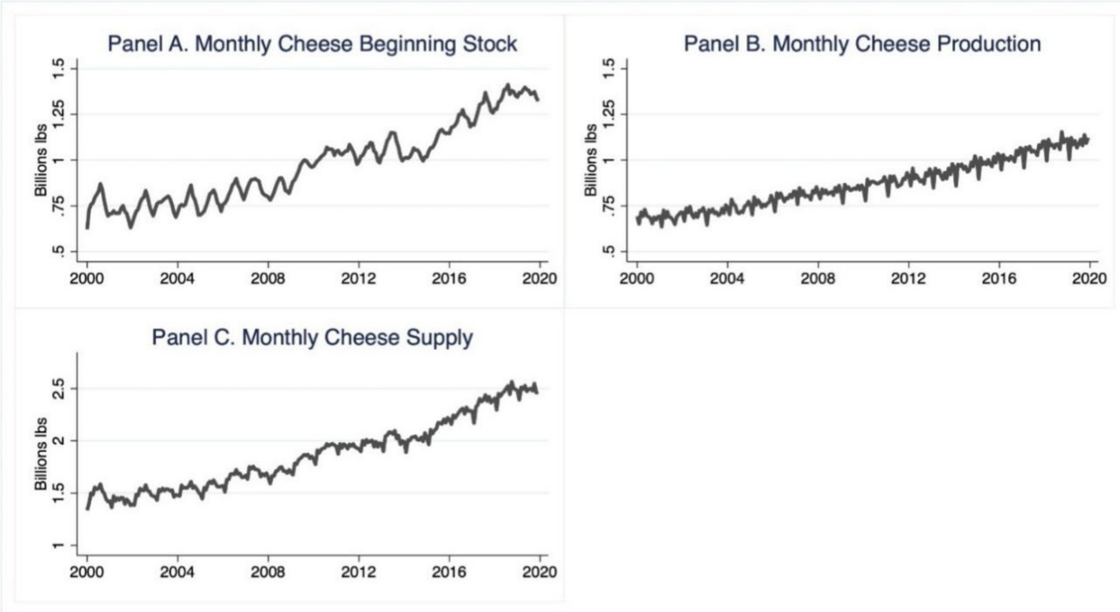

Figure 1. Cheese storage, production, and supply.

Source: Monthly cheese beginning stock (Panel A), production (Panel B) and supply (Panel C) from USDA-ERS [5]. Note that supply in Panel C is the sum of beginning stock, production, and import (not shown here).

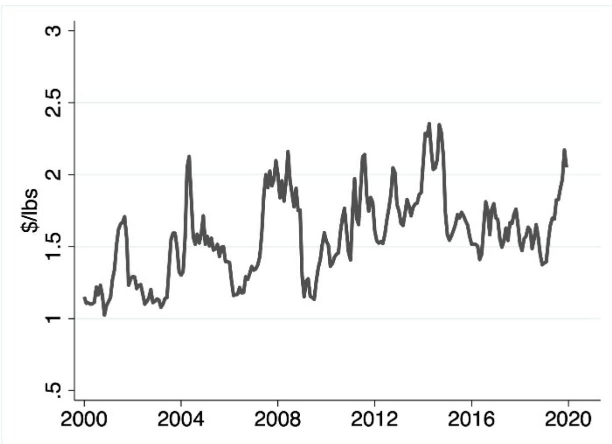

Figure 2. Cheese prices.

Source: Monthly average market prices for cheddar cheese from USDA-AMS (USDA, AMS, 2020b).

in this study is grounded in this theoretical foundation. To provide an intuitive representation of the oligopolistic market structure Figure 3 is presented. In this illustration, the horizontal axis represents the quantity of cheese, q, and the vertical axis represents the cheese price, p. Each point in Figure 3 indicates an equilibrium where supply (S) and demand (D) curves intersect at a specific period in time. Over time, demand and supply curves shift up or down based on supply and demand shifters; for example, milk production affects cheese supply curves and household income influences the cheese demand curves. As a result, multiple supply-demand equilibrium points exist, reflecting different supply-demand interactions over time. The fitted line connecting these equilibrium points represents the long-run relationship (LR) depicted in Figure 3 represents, denoted as $p = f(q)$. Panel A in Figure 3 demonstrates a negative long-run relationship between price and quantity, while Panel B shows a positive relationship. This long-run relationship depends on how supply and demand shift over time. For the period in this study, the growth in cheese supply has outpaced changes in demand, resulting in a negative long-run relationship referred to as "price softening". The theoretical underpinnings and graphical representation provided in Figure 3 help to understand the relationship between cheese price and supply within the context of an oligopolistic market structure.

Market analysts interviewed by financial press suggest that the surge of inventory has depressed prices, despite recent increases in cheese consumption [18]. The hypothesis for this study is taken from these previous assertions, with the primary objective of estimating the market impact from an overly abundance of cheese supply affecting its market price, including the long-run price effect. To date, there has been a research gap in examining the short and long-term implications on cheese price and its variability resulting from the excessive growth of cheese supply. Persistent declines in cheese prices may adversely affect cheese and dairy industry players in the long run, potentially bringing about more industry consolidation [19]. To address this matter, and assume an oligopolistic market

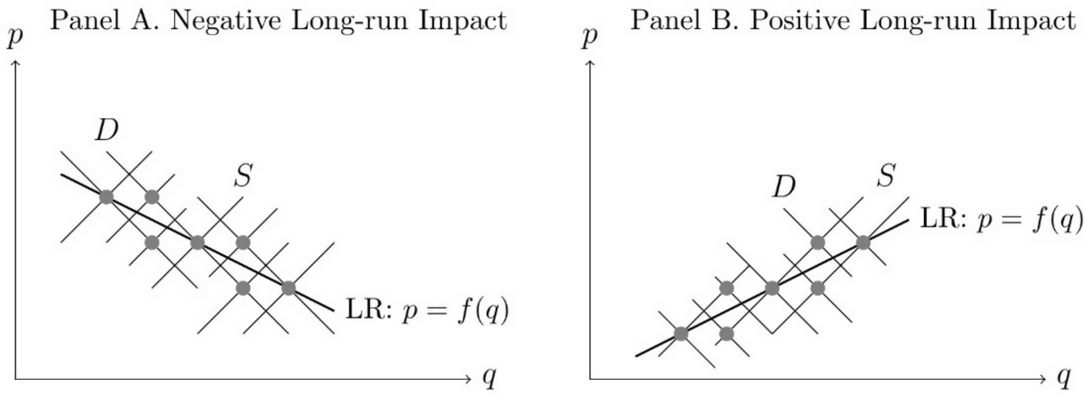

Figure 3. Long-run impact of cheese supply on prices.

Source: Created by authors.

structure, this study employs an autoregressive distributed lag model (ARDL) to estimate price as a function of supply. Taking 2019 as a reference year, empirical results indicate that a 1% increase in cheese supply (equivalent to approximately 24.9 million pounds/month) immediately leads to a 0.87% decrease in cheese prices (approximately 1.5 cents/pound). Moreover, this 1% surge in cheese supply resulted in a 1.89% decrease in prices (roughly 3.4 cents/pound) after a period of six to seven months.

The theoretical implications of this study can be summarized in two key aspects. Firstly, by examining the relationship between cheese supply and prices within an oligopolistic market structure, this study significantly contributes to the theoretical understanding of market dynamics within the cheese industry. As previously mentioned, it shed light on the intricacies of pricing mechanisms and the influence of supply on market outcomes. This analysis augments knowledge of how market forces operate in this specific industry context. Secondly, the findings of this study hold practical significance for policymakers, industry stakeholders, and market participants. The insights gained regarding the impact of cheese oversupply on prices can serve as valuable guidance for better decision-making processes related to supply management, risk mitigation, and investment strategies. By providing empirical evidence and an increased understanding of the dynamics at play, this study supports the formulation of effective policies and aids in informed strategic decision-making within the cheese industry.

The remainder of this study is organized as follows. The next section reviews prior studies that have researched the U.S. cheese market. Section 3 introduces data and examines the (estimated) ARDL model and its pertinence. Results, discussions, and implication remarks follow in Sections 4 and 5.

2. Literature Review

Numerous studies investigating the U.S. cheese sector have addressed matters of cheese markets. Recently Bolotova [20] investigated the spot cheese market and its behavior along different periods of FMMOs finding that this relation has intensified over the years, with increasing effects on price volatility. Tejeda and Kim [21] investigated price dynamics among different cheese varieties finding periods where prices of American and Other cheese types were decoupled. Studies addressing cheese market structure and its oligopolistic nature include Mueller and Marion [15] who examined the trade behavior of leading cheese companies on the National Cheese Exchange, which despite trading less than 0.2% of all cheese sold in the U.S. provided market signals for formula-pricing of 90-95% of all bulk cheese, and found evidence of market manipulation from oligopolistic cheese producers. Arnade et al. [16] investigated the level of retail competition in the U.S. cheese market, finding that the existence of price markups suggested the presence of imperfect competitive behavior. Kim and Cotterill [22] investigated pass-through rates for processed cheese under market conditions and found significant differences in these rates for processed cheese under different market conditions regime in comparison to being under a Nash-Bertrand price competitive regime. For this latter, the pass-through rate was at least three times that of under collusion.

More recently, Bolotova and Novakovic [4] investigated the farm-to-wholesale price transmission process affecting the pricing practices used by Chicago Mercantile Exchange (CME) cheese wholesalers. Findings revealed that pricing strategies used by cheese sellers are consistent with oligopolistic behavior. Lopez et al. [23] determined the level of oligopoly markups above that of being perfectly competitive markets for several U.S. food processing industries by estimating the associated Lerner index, which measures the amount of market power (0 = perfect competition, 1 = monopoly), and found a moderate degree of market power for the cheese manufacturing industry, i.e. corroborating prior results of the presence of oligopolistic behavior. The softening of cheese prices from sizable increases in supply has not been investigated and this study attempts to fill this gap in the literature.

3. Materials and Methods

Monthly average market prices of cheese for the period of January 2000 to December 2019 from the Agriculture Marketing Service (AMS) of USDA for the dairy program are used USDA AMS [24]. Monthly U.S. cheese supply data include production, beginning stock, and imports for the same period and are collected from the Economics Research Service (ERS) of USDA ERS [5]④. Table 1 provides a summary of the data. Cheese supply is the sum of beginning stock, production, and imports (imports not shown in Figure 1). From Table 1, cheese supply is on average 1.87 billion pounds per month (beginning stock 0.98 billion pounds plus production 0.87 billion pounds plus import 0.03 billion pounds) during the sample period, having a consistent upward trend, as shown in Panel C in Figure 1. The average monthly cheese supply during 2018 and 2019 surpassed 2.47 billion pounds after considering the average monthly beginning stock of 1.36 billion pounds. Conversely, the price of cheese displays a relative opposite trend especially from 2015 to early 2019, a period of steady increase in cheese stock. As noted, many market analysts quoted in the business media have expressed concern about cheese prices falling during this period [7,25,26].

The empirical strategy to quantify the impact of unprecedented growth in cheese supply on both short-run and long-run market prices is based on the oligopolistic cheese market structure [4,15]. From prior findings of the U.S. cheese sector depicting an oligopolistic market behavior, it is anticipated that some degree of market power is exerted. In the classical oligopoly market model, e.g., the Cournot model, the market price is a function of total supply [17]. As such, we estimate cheese price as a function of total supply. In addition, the price from a previous period may affect the current price since cheese is a storable commodity, i.e., affecting the adjustment of the supply schedule. To reflect the unique characteristics of the cheese market in the U.S., an innovative approach utilizing an autoregressive distributed lag model (ARDL) considering cointegration [27] is adopted in this study. The ARDL model provides a robust framework for investigating this matter. By employing the ARDL model, we are able to examine both the short-run and long-run relationships between cheese prices and cheese supply, capturing the dynamics of the market over time. An advantage of using the ARDL model with a cointegration approach is that the dependent variable, in this case, cheese prices, is allowed to be non-stationary [28]. Another benefit of using the ARDL model is that through reparameterization we can construct an error correction model, which enables us to find the short-run and long-run effects.

Table 1. Descriptive statistics (Jan 2000-Dec 2019, 240 observations).

Variable	Mean	Std. Dev.	Max	Min
Beginning stock (million lbs.)	976	209	1,413	621
Production (million lbs.)	868	133	1,154	636
Import (million lbs.)	27.2	6.7	46.0	1.4
Supply (million lbs.)	1,871	335	2,567	1,335
Price ($ per lbs.)	1.58	0.98	2.35	1.02

Sources: USDA AMS [24] for cheese prices and USDA ERS [5] for beginning stock, production, and import. Supply is the sum of beginning stock, production, and import.

Applying Kripfganz and Schneider [29], the ARDL (*p, q*) model is expressed by:

$$P_t = c_o + \sum_{i=1}^{p} \phi_i P_{t-i} + \sum_{j=0}^{q} \beta_j S_{t-j} + \varepsilon_t \tag{1}$$

where P_t *is* cheese prices at time *t*, and represented as the sum of lagged cheese prices and the sum of lagged cheese supply, S_t. Both P_t and S_t may be stationary, non-stationary or cointegrated [27,28]. The optimal lags of *p* and *q* are determined by minimizing information criteria such as the Akaike information criterion (AIC) or the Bayesian information criterion (BIC). The error term ε_t is assumed to be serially uncorrelated. Note that ordinary least squares (OLS) is used to estimate model in Equation (1) even though there are lagged dependent variables present on the right-hand side [30]. Pesaran and Shin [28] showed that the OLS estimators of the parameters in Equation (1) are $\sqrt{T}$-consistent and asymptotically normal, in other words, $\sqrt{T}(\boldsymbol{\Phi}, \widehat{\boldsymbol{\Phi}}) \xrightarrow{\mathrm{d}} \mathrm{N}(\mathbf{0}, \sigma^2\mathbf{I})$ where $\boldsymbol{\Phi} = [\phi_i, \beta_j]'$.

A trend variable is added to Equation (1) since visual inspection indicates a possible positive trend in cheese prices, as observed in Figure 2. To control for seasonality, 11 monthly dummies are also included in Equation (1). Cheese prices and supply are log-transformed and thus the relationship is in proportional or percentage terms.

The error correction form of the ARDL model can be

④ This study aggregates American and Other-than-American cheese types.

formulated by reparameterization in terms of the lagged levels and the first differences of P_t and S_t [29], and is expressed by:

$$\Delta P_t = c_o - \alpha(P_{t-1} - \theta S_{t-1}) \sum_{i=1}^{p-1} \psi_{pi} \Delta P_{t-i} + \sum_{j=0}^{q-1} \psi_{sj} \Delta S_{t-j} + \varepsilon_t \quad (2)$$

where α is the speed of adjustment (or error correcting) coefficient, defined by:

$$\alpha = 1 - \sum_{i=1}^{p} \phi_i \quad (3)$$

The expression $P_{t-1} - \theta S_{t-1}$ from Equation (2) can be interpreted as the long-run equilibrium denoted by LR, the fitted line, in Figure 3. When cheese prices and/or cheese supply deviates from the long-run equilibrium (LR), cheese prices and/or cheese supply adjust to restore the equilibrium relation at the speed of α. A value of $\alpha \approx 0$ implies a very slow adjustment back to the long-run equilibrium. Thus the value of α measures how fast cheese prices react to a deviation from the long-run relationship, LR. The long-run effects parameter, θ, is computed by:

$$\theta = \frac{\sum_{j=0}^{q} \beta_j}{\alpha} = \frac{\sum_{j=0}^{q} \beta_j}{1 - \sum_{i=1}^{p} \phi_i} \quad (4)$$

Coefficient θ describes the equilibrium effect of supply on cheese prices in the long run. The short-run coefficients, ψ_{pi} and ψ_{sj} in Equation (2) explain the short-run fluctuations not due to deviations from the long-run equilibrium. A value of ψ_{sj} being close to one in absolute terms indicates very rapid price adjustment after a change in cheese supply.

To check for the existence of the long-run relationship in Equation (2), a bounds test is suggested by Pesaran et al. [27]. The null hypothesis is that there is no long-run relationship between cheese prices and cheese supply.

$$H_0^F: \alpha = 0 \text{ and} \sum_{j=0}^{q} \beta_j = 0 \quad (5)$$

If H_0^F is rejected with F-test, a t-test is required to test whether α is zero or not.

$$H_0^t: \alpha = 0 \quad (6)$$

A long-run relationship between the price of cheese and cheese supply may be confirmed by rejecting both previous F-test and t-test. Lastly, the proportion of ψ_{s1} (contemporaneous adjustment) to θ (long-run adjustment) enables to measure the degree of relationship between cheese price and supply, i.e., how much of the price change occurs immediately.

4. Results

Empirical results from estimating Equation (1) for the price of cheese and its supply, between January 2000 and December 2019, are presented. The optimal lags for cheese supply and cheese prices were selected by minimizing BIC resulting in $p = 2$ and $q = 1$. Table 2 presents the top three ARDL models with the lowest BIC for comparison; as mentioned ARDL (2,1) is found to be the preferred resulting model. Note that the bounds test confirms that there is a long-run relationship between the price of cheese and cheese supply (F-stat = 11.79 and t-stat = 7.30; both H^F and H^t from Equations (5) and (6) are rejected at 1% significant level).

The optimal model ARDL (2, 1) from Equation (1) is expressed by:

$$\begin{aligned} \ln P_t = {} & c_o + \phi_1 \ln P_{t-1} + \phi_2 \ln P_{t-2} + \beta_0 \ln S_t \\ & + \beta_1 \ln S_{t-1} + \delta t + \sum_{m=1}^{11} c_m D_m + \varepsilon_t \end{aligned} \quad (7)$$

where β_0 is interpreted as the concurrent (instantaneous) supply effect, t is a trend and D_m is a monthly dummy (results are not reported in Table 2 to save space and are available upon request).

The coefficients from Table 2 are not easy to interpret because there are lagged dependent and independent variables. As discussed in the previous method section, a reparameterization of the estimated parameters permits converting the model into an error correction form as in Equation (2), from which estimated results are in Table 3. The long-run coefficient, θ, from Equations (2) and (4) is in the LR row of Table 3, representing the long-run effects of cheese supply on the price of cheese.

The model ARDL (2, 1) from Equation (7) is rewritten in error correction form as follows:

$$\begin{aligned} \Delta \ln P_t = {} & c_o - \alpha(\ln P_{t-1} - \theta \ln S_{t-1}) + \psi_{p1} \Delta \ln P_{t-1} \\ & + \psi_{s1} \Delta \ln S_t + \delta t + \sum_{m=1}^{11} c_m D_m + \varepsilon_t \end{aligned} \quad (8)$$

As mentioned, the coefficient of $\Delta \ln S_t$ from Equation (8), ψ_{s1} measures the contemporaneous effect on the price of cheese due to changes in cheese supply. Table 3, $\widehat{\psi_{s1}} = -0.866$ with p-value of 0.02, implies that 1% increase in supply leads to an immediate 0.87% decrease in cheese prices. The estimated value of α, the speed of adjustment coefficient, is –0.164. This suggests that it takes about $\frac{1}{0.16} \approx 6.3$ months to correct an equilibrium disturbance. The estimated parameter, θ, which indicates the long-run effect of an increase in cheese supply on its prices, is –1.891. In other words, a 1% increase in cheese supply results in a 1.89% decrease in cheese prices in the long run. Moreover, the proportion of ψ_{s1} (contemporaneous adjustment) to θ (long run adjustment), $\frac{\widehat{\psi}_{s1}}{\widehat{\theta}} = 0.46$, which indicates that the immediate change in cheese prices is 46% of the long run change.

5. Conclusions and Implications

The present study seeks to determine the extent that effects from a substantial growth in cheese supply have had on the decline of its prices. This situation not only affects the cheese sector stakeholders but also the milk prices of dairy producers through FMMOs. Previous studies have characterized the cheese market as having an oligopolistic nature, with its prices being a function of supply. Under an oligopolistic market scenario, we make use of monthly cheese prices and supply data from 2000 to 2019 to estimate an ARDL model and quantify the market effects.

Table 2. ARDL model results.

	ARDL (2,0)	ARDL (2,1)	ARDL (3,1)
ln P_{t-1}	1.1357***	1.1224***	1.1686***
	(0.064)	(0.064)	(0.067)
ln P_{t-2}	–0.3086***	–0.2860***	–0.4494***
	(0.065)	(0.065)	(0.099)
ln P_{t-3}			0.1451**
			(0.067)
ln S_t	0.3974**	1.1754***	–1.0991***
	(0.178)	(0.369)	(0.370)
ln S_{t-1}		0.8661** (0.362)	0.8733** (0.359)
Trend	0.0012** (0.0005)	0.0010** (0.0005)	0.0008 (0.0005)
Constant	0.1554**	0.1287**	0.0951
	(0.062)	(0.063)	(0.065)
Obs	238	236	237
Adj R^2	0.878	0.877	0.881
F-stat	114.4[0.00]	105.6[0.00]	103.4[0.00]
BIC	–533.79	–534.56	–534.09

Note: *, **, and *** indicate the significance at 10%, 5% and 1%, respectively.

Results for monthly dummies are not reported to save space, which are available upon request.

P_t represents cheese prices at time t and S_t is cheese supply at time t.

Numbers in brackets in F-stat row are p-values associated with the F-stats.

Empirical results indicate that the recent substantial growth in cheese supply indeed significantly decreased cheese prices. Results from an estimated optimal ARDL (2,1) model find that a 1% increase in cheese supply leads to a 0.87% decrease in cheese prices in the short run and a 1.89% decrease in the long run. That is, for a monthly average supply in 2019 of 2,486 million pounds, a 1% increase in supply is roughly equivalent to 25 million pounds, which would depress cheese prices by 1.53 cents/pound in the short run and 3.32 cents/pound in the long run. Implications from the findings are compelling. Considering 2019 as the reference year, and assuming all other things being equal, if cheese supply had decreased by 7.5% (roughly, 186 million pounds), 2019 cheese prices would have on average been around $2/pound; however, the actual average price was about $1.75/pound.

In conclusion, this study carries important theoretical implications that contribute to our understanding of market dynamics within the cheese industry. By examining the relationship between cheese supply and prices within an oligopolistic market structure, we have shed light on the intricacies of pricing mechanisms and the influence of excessive supply growth on market outcomes. This analysis enriches our knowledge of how market forces operate within this specific industry context. Moreover, the practical implications of our findings hold significant relevance for policymakers, industry stakeholders, and market participants. The insights gained from this study regarding the impact of the unprecedented growth of cheese supply on prices provide valuable guidance for decision-making processes related to supply management, risk mitigation, and investment strategies. Empirical evidence and a deeper understanding of the dynamics at play can inform the formulation of effective policies and facilitate informed strategic decision-making within the cheese industry. It is crucial to note that discussions surrounding cheese prices should consider the unusual and significant growth in cheese supply, as revealed in this study. Such considerations have implications for risk management and trade policy analysis. By incorporating these insights, stakeholders can navigate challenges posed by the mentioned cheese supply phenomena studied and make well-informed decisions to foster a viable and sustainable cheese sector.

There are several potential avenues for future research based on the findings and implications of this study. Firstly, while this study primarily focused on the impact of the unprecedented growth of cheese supply on prices, future research could expand on this by examining the role of demand factors in shaping cheese prices. Investigating the relationship between consumer preferences, demographic

Table 3. ARDL in error correction form.

		ARDL (2,0)	ARDL (2,1)	ARDL (3,1)
ADJ	$\ln P_{t-1}$	–0.1730***	–0.1636***	–0.1357***
		(0.035)	(0.035)	(0.037)
LR	$\ln S_t$	–2.2980***	–1.8910**	–1.6636
		(0.839)	(0.914)	(1.141)
SR	$\Delta\ln P_{t-1}$	0.3086***	0.2860***	0.3043***
		(0.065)	(0.065)	(0.065)
	$\Delta\ln P_{t-2}$			–0.1451**
				(0.067)
	$\Delta\ln S_t$		–0.8661**	–0.8733**
			(0.362)	(0.359)
	Trend	0.0012**	0.0010*	0.0008
		(0.0005)	(0.0005)	(0.0005)
	Constant	0.1554**	0.1266*	0.0951
		(0.062)	(0.064)	(0.065)

Note: *, **, and *** indicate the significance at 10%, 5% and 1%, respectively.

Results for monthly dummies are not reported to save space, which are available upon request.

ARDL (p, q) represents autoregressive distributed lag model; p is number of lags of autoregressive terms, P_{t-i}, and q is number of distributed lag terms, S_{t-j}. See Equation (1).

ADJ represents α, the speed of adjustment, in Equation (3).

LR represents θ, the long run coefficient, in Equation (4).

SR represents ψ_{pi} and ψ_{sj}, the short run coefficients, in Equation (2).

changes, and market demand could provide a more comprehensive understanding of the dynamics of price formation in the cheese industry. Secondly, further research could delve into the broader implications of supply chain efficiency and coordination on market outcomes. Factors such as transportation costs, inventory management, and distribution strategies can significantly impact the overall functioning of the cheese market. Exploring these aspects can provide insights into how supply chain dynamics affect price dynamics and market outcomes. Thirdly, considering the growing export market for cheese, future research could explore the impact of international trade on domestic cheese prices and market integration. Analyzing trade patterns, tariffs, and trade agreements can offer valuable insights into the relationship between global market dynamics and domestic cheese prices.

Lastly, it is important to address a caveat. This study assumed an oligopolistic market structure in the cheese industry based on previous studies [4,15,16]. However, it is essential to acknowledge that market structures may evolve over time, and the assumption of an oligopoly in the U.S. cheese market may no longer be the case. Future research could investigate the current market structure and its implications for price dynamics to provide updated insights.

Authors Contributions

The authors confirm contribution to the paper as follows: study conception and design: Z. Wang, H. Tejeda, and M-K. Kim; data collection: Z. Wang and W. Siu; analysis and interpretation of results: Z. Wang, H. Tejeda, M-K. Kim and W. Siu; draft manuscript preparation: Z. Wang, H. Tejeda, M-K. Kim and W. Siu. All authors reviewed the results and approved the final version of the manuscript.

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Data Availability

Data is available upon request (all the data used in the manuscript are available from the public domain). Please contact the corresponding author.

Conflict of Interest

Authors certify that we have no affiliation with or involvement in any organization or entity with any financial interest in the subject matter or materials discussed in this manuscript.

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